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Introducing a Complex Systems Paradigm

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Introduction

Commercial driver sleep health and safety: Reductionism and policy resistance

Sleep health and safety of commercial drivers: Sleep is vital to mental and physical health. Adequate sleep bolsters neurocognitive functioning, protects against fatigue and excessive daytime sleepiness, and generally supports a healthy lifestyle [1]. These attributes are particularly important for commercial drivers, as fatigue-related safety failures among these professionals can have catastrophic consequences for public safety. Unfortunately, commercial drivers encounter sleep issues related to the work organization of commercial driving. Commercial driving is uniquely influenced by a highly regulated environment, where federal and corporate policies exerting influence on the work and personal lives of drivers in ways unlike other occupations. In the trucking industry, for example, deregulation in the early 1980s drastically changed the structure of the industry and created a hypercompetitive business environment. As a result, commercial drivers saw declines in wages, working conditions, and bargaining power as the influence of unions declined [2].

With drivers and their unions no longer influential enough to ensure safe working conditions, the responsibility fell upon federal policymakers; further, the US Department of Transportation assumed responsibility for ensuring driver fitness, including adequate sleep. Regulations pertaining to sleep, titled "hours-of-service" (HOS) rules, dictate shift lengths, weekly work hours, and rest breaks. Although these statutes have gone through several permutations, their effectiveness in ensuring adequate commercial driver rest is specious, as they fail to address the root causes of driver sleep problems. Commercial driving continues being a hypercompetitive industry, where shippers and consignees dominate the market and set pickup and delivery schedules [3]. As a result, drivers are under pressure to complete "just-in-time" deliveries [4] and are beholden to pickup and delivery windows which may be at all times of the night-both of which require work shifts that conflict with circadian rhythms. This competition is exacerbated by the depleted labour pool, where a growing commercial driver shortage [5] amplifies pressures placed upon drivers to be productive, often requiring health-compromising behaviors on the part of drivers. Further, commercial drivers-exempt from the Fair Labor Standards Act [2]-are underpaid and frequently perform work for which they are not compensated. In response, drivers work longer to maintain their livelihood [6], and in the process frequently violate HOS rules by abbreviating mandated rest periods and extending working and driving hours beyond the mandated legal limit [7]-behaviours which reduce sleep and compromise safety.

Commercial drivers thus experience long work hours, shift work, and tremendous job strain [7,8]. Further, the locations where commercial drivers obtain sleep are problematic. Because many drivers only return home a few times per month, sleeper berths are sites of the bulk of sleep time. However, because of various factors at park locations (e.g., noise, extreme ambient air temperature, air pollution), sleep is often interrupted, leading to chronic sleep deprivation [6]. Drivers consistently report reduced sleep quality and duration, chronic sleep disturbances and sleep deprivation, and chronic fatigue [9,10]. Unsurprisingly, prevalence of sleep problems, including disordered sleep, is heightened among commercial drivers [11,12].

In sum, the long work hours, fragmented and erratic work shifts, repeatedly perturbed circadian rhythms, reduced sleep duration and quality, and sleep disorders endemic to commercial driving wreak havoc on the mental and physical health of commercial drivers [13-17]. Resulting sleep problems generate fatigue and result in impaired driving performance due to excessive daytime sleepiness and reduced alertness [18,19]. Impaired driving performance results in injury and death for drivers and the motoring public, as well as having broad ramifications for governments, health care systems, and transportation and warehousing companies [15]. Further, changes in body composition and excess weight gains related to poor sleep health and exacerbated by other interacting factors generate multiple cardio metabolic comorbidities [15-17]. Interacting sleep problems and cardio metabolic comorbidities further exacerbate fatigue and accident rates [18] and substantially diminish commercial drivers' life expectancies [20]. These issues continue to plague drivers and vex prevention efforts.

Limitations of reductionist approaches to commercial driver sleep health

Epidemiological research in commercial driver sleep health has generally followed a traditional reductionist paradigm, where potential risk factors are analysed in isolation, with a goal of increased understanding and predictability [21,22]. The dominance of this paradigm conceptually, theoretically, methodologically, and analytically has persisted for centuries and is institutionally entrenched [23,24]. However, many real world problems cannot be adequately investigated solely using these approaches [25], including commercial driver sleep health.

Conceptually and theoretically, reductionism contributes to flawed mental models of complex issues, resulting in too narrow of boundaries and overemphasizing factors which are proximal across space, time, and levels of influence. Upstream distal factors-those which dictate work organization, for example, such as labor policies related to deregulation and driver compensation-are neglected in reductionist-oriented mental models, as are broad spatiotemporal influences and outcomes. Guided by such narrow mental models, corresponding etiological models place causal factors into "silos" to be modeled and analyzed in the pursuit of specific cause-effect relationships [22,26].

Rather than for explanatory reasons, this compartmentalization is often for pragmatic reasons, such as for convenience [27] or to gain tractability of problems that are seemingly daunting in their complexity. Methodologically, reductionist approaches seek internal validity, with the randomized clinical trial considered the optimal experimental design [28]. However, while maximizing internal validity, these methodological designs cannot capture distal outcomes, structural outcomes, or contextual or ecological effects [21,29]. Analytically, linear statistics are applied in order to understand proportional relations among variables assuming unidirectional causality, which then provides guidance toward which factors to include in our conceptual and analytical frameworks [21,30]. Traditional statistics are inherently reductionist [29], and characteristics of many real-world problems conflict with these analyses. Not only are most linear statistics limited to a single level of influence [29], their assumptions regarding cause-effect relationships-including that these relationships are linear and independent [26]-contradict reality.

Because of the limitations inherent to reductionism, these approaches may prevent researchers from recognizing the nonlinear nature of system elements [31]. Interacting and interrelated factors are problematic to reductionist approaches, and satisfactory means for incorporating time-delayed effects and phenomena such as emergence are lacking in the realm of reductionism [31,32]. This paradigm also cannot fully describe structural, multilevel pathways of influence, especially policy-level influences [33]. Even sophisticated linear analytical techniques cannot handle feedback loops (where part of an output is used for new input), threshold effects (a sudden and radical change; also known as a tipping point), and other types of nonlinearity [29,33]. For example, sophisticated multilevel modelling rests on regression techniques and thus shares the limitations of regression analysis, including the inability to capture these complex phenomena [34]. Interaction among system elements violates the assumption of independence of observations in regression [35]. Ultimately, reliance on reductionist approaches has proven prohibitive in understanding the true nature of system behaviour, with implications for intervention efforts [32].

Evidence from interventions oriented toward improving commercial driver health, including their sleep health, suggest that the utility of reductionist approaches for guiding such endeavours may be of limited utility. Prevention guided by this narrow worldview has resulted in underwhelming and ineffective, or "low-leverage," intervention efforts focused on alleviating symptoms of problems (e.g., managing driver sleep apnea), rather than the underlying causes of interacting and emergent organizational and individual inadequacies (e.g., improving work shift patterns) [22,36,37]. The small number of interventions aimed at improving driver sleep health has been individually based and reactive. These interventions usually target a small number of components within a broader complex system and based on the assumption that small remote inputs (e.g., sleep disorder screening) can produce analogous outputs (e.g., fewer sleep disorders) that can ultimately improve sleep health and highway safety [15,19,37,38]. For example, one major trucking company implemented a sleep apnea initiative that consisted testing and provision of medical equipment [19]. Broader wellness initiatives offered by transport carriers generally feature activities such as wellness coaches, education campaigns, and health assessments [19]. While these efforts have resulted in modest short-term return on investment [19], broader macro structural factors impacting the work organization of commercial driving have been unchanged. As a result, population-level health and safety outcomes continue to decline [39]. These interventions overlook the complexity of systems, such as commercial driver health. They also often exhibit policy resistance-where our actions not only fail to solve problems, but in fact may cause or exacerbate them [22]. An example of policy resistance in commercial driver sleep health can be seen in the outcomes of federal hours-of-service regulations mentioned previously. These regulations seek to ensure adequate rest among commercial drivers; instead, not only do they fail to ensure adequate sleep in accordance with circadian rhythms, they have also contributed to both increased mental strain resulting from loss of job control and increased social isolation among drivers [40].

Commercial driver sleep health: In need of a complex systems paradigm

Sleep health as a complex system: Commercial driver sleep health is a complex adaptive system that involves a plethora of interconnected, nonlinear, evolving, adaptive, and self-organizing elements. Nonlinearities inherent to commercial driver sleep health suggest the potential for dramatic and sudden changes in system dynamics, where crossing a threshold (a "tipping point") results in a system "tipping" and undergoing a critical transition [41]. Following such an event, the system shifts to a new equilibrium state which may be very difficult, if not impossible, to reverse. These events are notoriously difficult to anticipate and represent nonlinearity, as a small change nudges the system toward a vastly different equilibrium [41]. In the case of commercial driver sleep health, such an event could prove cataclysmic and have far-reaching consequences beyond the transportation sector to impact the broader economy and public safety. Elements of the commercial driver sleep health system are governed by feedbacks, as well as by circular causality, where causes and effects mutually interact instead of functioning as a linear chain of events [22,36]. Interacting social, labor, and health policies, food policies and systems, broad work environment and organization, and no work conditions induce drivers' behavioural, physiological, and emotional responses that ultimately generate diminished health and safety [38]. These factors are heterarchical (as opposed to hierarchical) and interact in overlapping, divergent, and coexistent ways [42].

Feedback loop dynamics in sleep health and safety

Feedback loops are principal drivers of system dynamics that have been excluded from reductionist approaches. However, they may be especially important in health disparities [21]. These loops embody both circular causality of a system and interdependence among system elements, as the actions of elements "feed-back" to influence other elements in the system [22]. Feedback loops also are a source of nonlinear dynamics within a system which are sensitive to initial conditions [22] and can create exponential growth, leading to critical transitions [22]. System dynamics arise from two types of interacting feedback loops: Reinforcing loops, which are amplifying and exhibit self-growth; and balancing loops, which are stabilizing and seek equilibrium [22]. In Figure 1, we demonstrate two loops related commercial driver sleep health and safety and how they may interact. These loops are highly simplified, and thus are for demonstrative purposes only. Arrows indicate direction of influence. A positive sign at an arrowhead indicates influence in same direction (as one factor

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increases, the other increases, and vice versa), and a negative signs indicates influence in the opposite direction (as one factor increases, the other decreases, and vice versa). One is a reinforcing loop (as indicated by a "R"): Increased work shift irregularity leads to more sleep problems for drivers, which leads to more fatigue-related traffic accidents, which results into a smaller driver pool due to attrition, which leads to even more irregular and longer driver shifts due to driver shortage, which ultimately leads to even worse sleep problems for drivers. The other is a balancing loop (as indicated by a "B"): Increased fatigue-related traffic accidents of drivers leads to the need for more corporate health and wellness programs, which leads to fewer driver sleep problems, which ultimately leads to fewer fatigue-related traffic accidents.

Reductionist-oriented approaches emphasize internal validity; thus, they isolate and reduce. Randomized control trials seek to isolate cause-effect relationships, and intervention research consists of quasi-experimental designs which similarly attempt to isolate cause-effect relationships related to program components. Such emphases on internal validity sacrifice the possibility of unpacking the dynamic interactions and interrelationships between heterogeneous elements within a system across multiple levels of influence. Successfully intervening in such systems is predicated upon understanding these influences, which are embodied by feedback loop structures. Thus, in order to accurately delineate complex adaptive systems, it is essential to understand its feedback loop structure, as the overall dynamics of a complex system depend on which loops are dominant [36]. In Figure 1, dominance of the reinforcing loop creates runaway deterioration of commercial driver sleep health and safety, while dominance of the balancing loop maintains commercial driver sleep health and safety in a steady state. Thus, feedback structures represent high-leverage intervention points for generating sustainable and substantial change – points that cannot be identified and exploited through reductionist approaches.

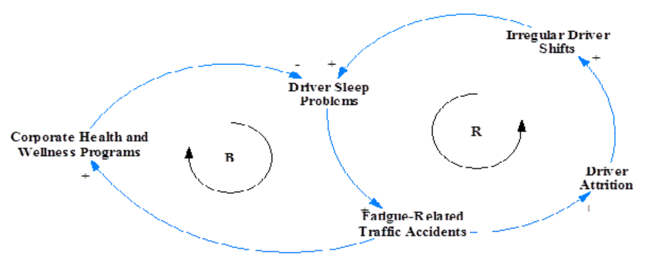

Figure 1: Hypothesized reinforcing and balancing loops in commercial driver sleep health and safety.

Systems simulation modelling in sleep health

Regardless of how sophisticated they may be, analytical tools grounded in reductionism are not suitable for studying complex adaptive systems such as commercial driver sleep health. Instead, analytical tools must be used that are capable of capturing feedback loops, nonlinear relationships, threshold effects, and structural influences (e.g., public policy) that shape and put the system in motion. Such tools are referred to broadly as computational modelling and simulation.

Computational modelling and simulation function as virtual worlds where limitless hypotheses can be tested in controlled experiments [22]. Based on the assumptions and inputs dictated by researcher(s), a simulation model is constructed, which is a simplified version of the reality of the problem under investigation [43]. Following efforts to ensure model validity, the researcher(s) then put the simulation model "into motion" [44] and run simulation experiments. Computational modelling and simulation can be used at various stages in a research endeavor and for multiple purposes. Basic research can be conducted, such as testing counterfactual simulations and exploring conceptual models [21,35]. Simulation experiments can also aid in identifying critical high-leverage points and optimal interventions or policy decisions by running multiple scenarios and examining outcomes [36]. By their ability to compare intervention or policy alternatives, these simulations can make a compelling argument for specific intervention or policy strategies [45]. Interventions targeting commercial driver sleep health can be simulated using these tools as various intervention configurations, including those which cannot be tested in the real world [46], can be implemented in a virtual world to see both short- and long-term outcomes. Because the system under investigation is more realistically represented because of the capabilities of such tools, any unexpected "side effects" (i.e., the presence of policy resistance) of potential intervention configurations can be recognized.

Computational modelling and simulation circumvent many of the limitations of reductionist approaches. Computational modelling and simulation are more cost-effective and less time-consuming; further, because simulations do not require actual participants, they evade ethical concerns inherent to in vivo experimentation [47]. These tools also can examine distal outcomes across long time spans, often spanning decades, which is typically not possible using reductionist approaches.

Among the most prolific computational modelling tools which may be applied to commercial driver sleep health care system dynamics modelling and agent-based modelling. Each is particularly adept in examining factors and outcomes at various levels: the former for macro-level, and the latter for micro- and meso-levels [48]. Ultimately, interventions stemming from computational modelling and simulation provide the best opportunity to understand the complex root causes of driver sleep problems and generate sustainable improvements at the aggregate level [22].

Conclusion

Commercial driver sleep health is of vital importance to the economy and public safety. Best viewed as "syndetic" [49], drivers' sleep health issues comingle with work organization and other cardio metabolic risk factors to exacerbate resulting negative health and safety outcomes. This, along with its complex nature and function, underscore the need for effective multi-layered preventive interventions and policies. Reductionist approaches have guided intervention efforts thus far; however, the severe limitations of these approaches doom further efforts as this system continues to exhibit policy resistance. Policy resistance casts doubt on the likelihood of substantive positive change, and as the problem exacerbates, the pressure to mitigate its effects grows, and actions often sacrifice long-term sustainability for short-term solutions [22]. As the shortage of commercial drivers continues to climb [5], and as sleep health-related healthcare costs and accident rates for drivers continue to rise [18,50], pressure will further mount.

The theories and experimental and analytical techniques of complex systems science hold the promise to generate impactful and sustainable interventions. By conceptualizing commercial driver sleep health as a complex adaptive system and by engaging in computational modelling and simulation, dominant feedback loops can be uncovered and high-leverage intervention points can be identified. The sleep health of commercial drivers and resultant safety consequences will vex us no more.

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